Conodonts of the Estill Shale and Bisher Formation (Silurian, Southern Ohio): Biostratigraphy and Distribution[1]

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ABSTRACT. Representatives of 20 species of conodonts have been isolated from samples of the Silurian Estill Shale and Bisher Formation at four localities in southern Ohio. The Estill belongs in the *amorphognathoides* Zone and is late Llandoverian to early Wenlockian. The Estill-Bisher contact is an unconformity. In Adams and southern Highland counties, the Bisher belongs in the middle and upper *ranuliformis* Zone and is late early to possibly early middle Wenlockian; in northern Highland County the Bisher belongs in the lower *ranuliformis* Zone and is middle early to late early Wenlockian. The Estill was deposited in a gradually shoaling sea that regressed from Adams and Highland counties in the early Wenlockian. The sea transgressed southward across the two counties later in the early Wenlockian and deposited the Bisher in a shallow, subtidal environment.

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INTRODUCTION

The Estill Shale and overlying Bisher Formation make up most of the lower Niagaran sequence (Silurian) in Adams and Highland counties in southern Ohio. The first, and only detailed, published report on conodonts from either the Estill or Bisher was by Rexroad and Nicoll (1972), who sampled the Estill Shale at numerous localities in east-central Kentucky and in southern Adams County, Ohio. They recognized 65 named conodont species in form-element taxonomy, which characterized two conodont assemblage zones. Kleffner (1984) and Rexroad and Kleffner (1984) briefly summarized information about Estill and Bisher conodonts; Kleffner (1982) gave more detailed information on Estill and Bisher conodonts in an unpublished thesis.

Many Silurian conodonts have been shown to be excellent index fossils, as well as useful paleoecological indicators. Several of these are represented in the Estill and/or Bisher. The present study was undertaken 1) to develop a detailed conodont biostratigraphy for the Estill Shale and Bisher Formation, providing a means for dating, for more precise correlation, and for reevaluation of the nature of the Estill-Bisher contact and 2) to use conodont distribution in the formations to learn more about their depositional environments.

STRATIGRAPHIC SUMMARY

The Estill Shale was named by Foerste (1906) as a member of the Alger Formation for exposures near Estill Springs, just north of Irving, Estill County, Kentucky. The Estill Shale was raised to formational rank by Rexroad et al. (1965). The Estill overlies the Noland Formation in central and southern Adams County, and the Dayton Formation in northern Adams County and Highland County, Ohio. North of Fleming County, Kentucky, an unconformity separates the Noland and Estill (Rexroad and Kleffner 1984).

The Estill Shale consists predominantly of blue-green, gray-green, green, and brown shale. Shale beds are commonly blocky or massive in the lower part of the formation and silty and fissile in the upper part. The basal Estill commonly contains abundant glauconite, and in southern Ohio and northernmost east-central Kentucky, thin dolomite partings and red shale. Thin lenses or stringers of arenaceous dolomite are abundant in the upper Estill in southern Ohio. The thin, arenaceous dolomites are finely laminated (in most places indicating cross-bedding), extensively burrowed, and contain fucoidal markings. The Estill thins to the north and northwest in Adams and Highland counties, Ohio, and has an average thickness of 41 m in the former.

Foerste (1931) and Bowman (1956) collectively recognized representatives of 22 megafossil species in the upper Estill Shale, but the lower part lacked megafossils of any kind (Foerste 1931, Bowman 1956). Rexroad and Nicoll (1972), Kleffner (1982), and Rexroad and Kleffner (1984) have shown that, although much of the Estill may lack megafossils, microfossils (conodonts, ostracodes and scolecodonts are the most abundant) are common throughout the formation. Conodonts indicate that the Estill Shale was deposited during the *amorphognathoides* Zone, or during the late Llandoverian to early Wenlockian (Rexroad and Nicoll 1972, Kleffner 1982, Kleffner 1984, Rexroad and Kleffner 1984).

The Bisher Formation is the unit immediately above the Estill Shale in Adams and Highland counties, Ohio. Foerste (1917) named the Bisher as a member of the West Union Limestone of Orton (1871) and later (Foerste 1923) raised it to formational rank. The Bisher overlies the Estill with apparent conformity (Bowman 1956, Rexroad et al. 1965, Rexroad and Kleffner 1984), although the contact in most places is sharp and gently

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wavy (Rexroad et al. 1965). Kleffner (1984) suggested that the Estill-Bisher contact was an unconformity, at least locally in southern Ohio. The Bisher is conformably overlain by, and grades laterally into, the Lilley Formation (Bowman 1956).

The Bisher consists predominantly of medium- to dark-gray, fine-grained, argillaceous to silty dolomite that characteristically weathers to a buff or yellow-brown color. Locally, bioclastic or dense limestone predominates over the dolomite (Bowman 1956). The Bisher also contains interbedded dolomitic or silty dolomitic shales, commonly in the lower half of the formation. A 0.3 to 1.5 m thick fossiliferous horizon, termed the *Cryptothyrella* lithofacies by Bowman (1956), occurs 0.9 to 2.7 m above the base of the Bisher. The upper part of the formation is commonly cross-bedded in Adams County, Ohio. At most localities where the overlying Lilley is a massive crinoidal packstone-grainstone, the uppermost Bisher is transitional with the Lilley; unfossiliferous wackestone beds (Bisher lithology) alternate with crinoidal packstone-grainstone beds (Lilley lithology). The Bisher ranges from 7.6 to 25.9 m in thickness in southern Ohio and is on the average, 12.2 m thick in Adams County. It generally thins to the north and west in Highland County.

Foerste (1919, 1931) and Bowman (1956) collectively recognized representatives of 58 megafossil species in the Bisher. The *Cryptothyrella* lithofacies, the most persistent and lowest observed fossiliferous horizon in the Bisher, contains representatives of nearly every species recorded elsewhere in the formation (Bowman 1956). The remainder of the Bisher is poorly to only moderately fossiliferous. Although parts of the Bisher may lack megafossils, microfossils (conodonts, ostracodes, and sponge spicules are the most abundant) are common throughout the formation. Foerste (1931) used ostracodes to correlate the Bisher with the uppermost part of the Clinton Group of New York, which is late Llandoverian to middle Wenlockian in age according to Berry and Boucot (1970). Kleffner (1982, 1984) and Rexroad and Kleffner (1984) referred the Bisher to the *ranuliformis* and *amsdeni* conodont zones or to the partially equivalent *patula* conodont zone (early to middle Wenlockian, see Barrick and Klapper 1976).

MATERIALS AND METHODS

COLLECTING LOCALITIES. **(Sections numbered as in Fig. 1)** 1. Jacksonville Estill section (78MA and 80MA) and Bisher section (80MK), located on opposite sides of the same hill. The 78MA and 80MA is an exposure on the east side of Ohio State Route (OSR) 41, 0.6 km south-southwest of Jacksonville (Ohio coordinates: 4,308,700 m N; 287,750 m E. Lat. 38°54′10″N, Long. 83° 26′52″W). The 80MK is an exposure on the west side of old OSR 41 (no longer in public use), 0.5 km south, through a farmer's field, of Jacksonville, Meigs Township, Adams County, Ohio. (Ohio coordinates: 4,308,700 m N; 288,000 m E. Lat. 38°54′10″N, Long. 83°26′45″W. Peebles 7 1/2′, quadrangle).
2. Ohio State Route 32 section (83MK1). Exposures on south and

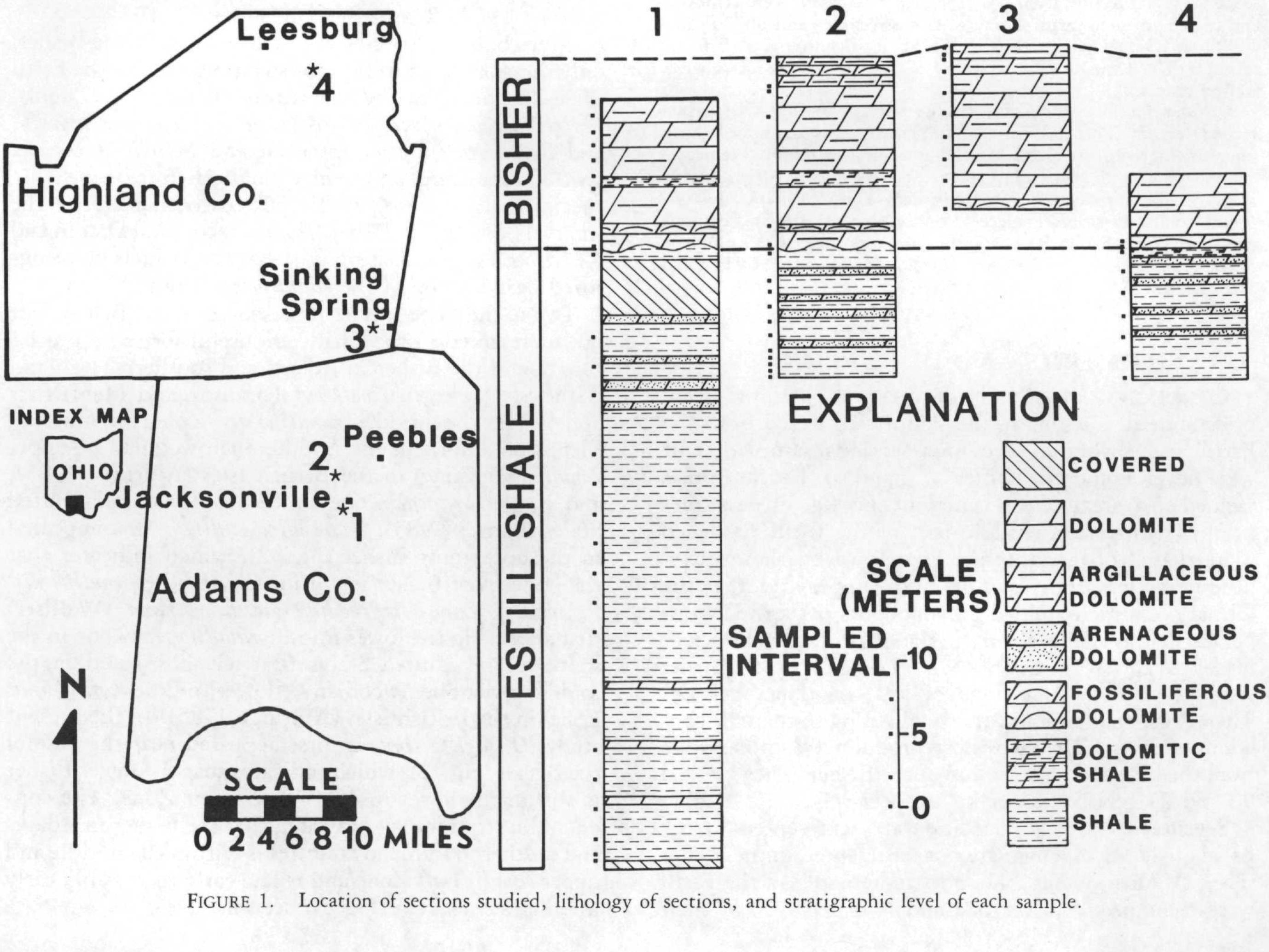

FIGURE 1. Location of sections studied, lithology of sections, and stratigraphic level of each sample.

north sides of OSR 32, 2.9 km west of intersection of OSR 32 and 41, Meigs Township, Adams County, Ohio. (Ohio coordinates: 4,312,500 m N; 287,000 m E. Lat. 38°56′15″N, Long. 83°27′30″W. Peebles 7 1/2′ quadrangle). Stop 5B in Rexroad and Kleffner (1984).

3. Sinking Spring section (81MAB and 83MK2). Exposure on north side of east-west road leading to Sinking Spring, just west of Baker Fork, 0.8 km west of Sinking Spring, Brush Creek Township, Highland County, Ohio. (Ohio coordinates: 4,327,120 m N; 292,630 m E. Lat. 39°04′14″N, Long. 83°23′40″W. Sinking Spring 7 1/2′ quadrangle). Locality 27 of Bowman (1956).

4. Leesburg section (81MA). Exposure on south bluff of Harden Creek, directly beneath a dead-end road, 5.8 km southeast of Leesburg, near Bridges, Fairfield Township, Highland County, Ohio. (Ohio coordinates: 4,353,400 m N; 284,300 m E. Lat. 39°18′20″N, Long. 83°30′05″W. Leesburg 7 1/2′ quadrangle). Locality 5 of Bowman (1956).

Samples were collected from the Estill Shale and/or Bisher Formation at four localities in Adams and Highland counties, Ohio (Fig. 1). Samples were collected at regularly measured intervals (0.5, 1.0, 1.5, and 2.0 m) in the Estill and Bisher. Sample weights averaged 5.6 kg for Estill samples and 6.4 kg for Bisher samples. All of the material in each sample was processed for conodonts.

Shale samples were disaggregated by soaking in kerosene overnight, draining, and then flushing with hot water to which a small amount of detergent was added. Crushed dolomite samples were disaggregated and reduced by placing 1-kg samples in a small, perforated bucket suspended in a larger bucket, to which was added 6 L of water and 750 mL of glacial acetic acid. The acid was changed as many times as necessary (generally twice) to completely disaggregate and/or dissolve the sample. The disaggregated shale and dolomite samples were then washed through 20- and 100-mesh sieves. Residues remaining on the sieves were collected and dried, but only 100-mesh residues were searched for conodonts. Large, 100-mesh residues were further concentrated by the use of tetrabromoethane and/or through magnetic separation. Residues were viewed with a binocular microscope at 12× magnification. All conodonts observed were removed and placed in microfossil slides. Microfossil slides and all 20- and 100-mesh residues were stored in the Micropaleontological Laboratories at The Ohio State University (OSU) under the designated section code.

A scanning electron microscope (Cambridge S4-10) with an attached camera (Polaroid Land, XL-55 film) was used for taking photomicrographs of selected conodonts for illustration. Elemental analysis of gray to black-gray conodonts was done with an energy dispersive x-ray analyzer (Tracor Northern TN-5500), used in conjunction with the scanning electron microscope. All illustrated specimens (see Appendix 1, Figs. 5 and 6) are kept under OSU numbers in the type collection of the Orton Geological Museum at The Ohio State University.

RESULTS AND DISCUSSION

Conodont Biostratigraphy. Conodonts were present in all but one of the samples collected from the Estill and Bisher at the four sections sampled, but were never abundant (Tables 1, 2 and 3). Estill samples yielded an average of 6.6 conodonts per kg. Five samples from the lower and middle part of the Estill produced more than 10 conodonts per kg. However, the greatest production was from a sample in the upper middle of the formation, which yielded 20 conodonts per kg. The upper Estill was the least productive part of the formation; it yielded an average of only 3.2 conodonts per kg. Bisher samples yielded an average of 5.9 conodonts per kg. There were four samples that yielded more than 10 conodonts per kg. The two most productive samples were from the base and near the top of the Bisher. They yielded 56 and 21 conodonts per kg, respectively.

Seventeen conodont species were represented in the Estill Shale, 11 of which are not represented in the Bisher (Fig. 2). Most of the conodonts represented in the Estill were recognized by Rexroad and Nicoll (1972) in their Estill conodont study. Conodont species not reported from the Estill in their study, but represented in the formation in this study, were *Ozarkodina hadra* (Nicoll and Rexroad), *Pterospathodus pennatus* (Walliser), *Pseudooneotodus bicornis* Drygant, *Pseudooneotodus tricornis* Drygant, and *Johnognathus huddlei* Mashkova. *Pterospathodus amorphognathoides* Walliser, the index for the conodont zone of that name, was represented in all but the uppermost Estill (Tables 1 and 2). Its lack of representation in the upper Estill is due to depositional environment restrictions on its distribution (see Depositional Environment for further discussion), and is not an indication that the uppermost Estill belongs in the succeeding conodont zone. The distribution of at least one and possibly two other species (*Carniodus carnulus* Walliser, *Ozarkodina hadra*) reinforced that interpretation.

Carniodus carnulus has never been reported from a zone succeeding the *amorphognathoides* Zone (Walliser 1964, Barrick and Klapper 1976, Uyeno and Barnes 1983, Barrick 1983, Aldridge 1985). *Carniodus carnulus* and *Ozarkodina hadra* were represented in a sample from the top of the Estill. In North America, the latter species has never been reported from a zone succeeding the *amorphognathoides* Zone (Barrick and Klapper 1976, Barrick 1983). In the British Isles, however, it has been reported to occur only in the succeeding zone (Aldridge 1985). Based on the conodont biostratigraphy, the Estill Shale is within the *amorphognathoides* Zone, and is late Llandoverian to early Wenlockian (Fig. 3). This agrees with previous age determinations (Rexroad and Nicoll 1972, Kleffner 1984, Rexroad and Kleffner 1984).

Nine conodont species were represented in the Bisher, only three of which were not also represented in the Estill (Fig. 2). Four (*Ozarkodina excavata* (Branson and Mehl), *Kockelella ranuliformis* (Walliser), *Pseudooneotodus bicornis*, and *Decoriconus fragilis* (Branson and Mehl)) of the six species that were represented in both formations, are species that Cooper (1980) reported to characterize the interval between his *Pterospathodus* Extinction Datum and *Kockelella walliseri* Datum, the latter of which he recognized near the top of the *ranuliformis* Zone.

Two of the three species represented in the Bisher, but not represented in the Estill, are useful for more precise zonation of the Bisher in Adams and southern Highland counties. *Ozarkodina confluens* (Branson and Mehl) first appears in the middle *ranuliformis* Zone on Gotland (Jeppsson 1984), in the middle Sheinwoodian (=upper *ranuliformis* Zone) in the British Isles (Aldridge 1985), and in the *amsdeni* Zone in the south-central United States (Barrick 1983). *Ozarkodina confluens* first appeared in the uppermost Bisher (Fig. 2), which indicates that the uppermost Bisher is within the middle *ranuliformis* to *amsdeni* Zone. *Ozarkodina sagitta rhenana* (Walliser) first appears in the lower middle *ranuliformis* Zone in the south-central United States (Barrick 1983) and in the middle lower Sheinwoodian (=lower middle *ranuliformis* Zone) in the British Isles (Aldridge 1985). In the present study, *O. sagitta rhenana* first appeared near the base of the Bisher (Fig. 2), which indicates that the lower Bisher is within the lower middle *ranuliformis* Zone. The conodont biostratigraphy indicated that the Bisher in Adams and southern Highland counties is within the middle and upper *ranuliformis* Zone and is late early to possibly early middle Wenlockian (Fig. 3, sections 1-3).

TABLE 1.

Conodont distribution in Estill Shale and Bisher Formation in Jacksonville-Peebles, Ohio, region.

Sample number*	Meters above Estill base	Meters above Bisher base	Conodonts per kilogram	*Carniodus carnulus*	*Decoriconus fragilis*	*Distomodus staurognathoides*	*Johnognathus huddlei*	*Kockelella ranuliformis*	*Oulodus petila*	*Oulodus* sp.	*Ozarkodina confluens*	*Ozarkodina excavata*	*Ozarkodina hadra*	*Ozarkodina polinclinata*	*Ozarkodina sagitta rhenana*	*Panderodus* sp. cf. *P. recurvatus*	*Panderodus unicostatus*	*Pseudooneotodus bicornis*	*Pseudooneotodus tricornis*	*Pterospathodus amorphognathoides*	*Pterospathodus pennatus procerus*	*Pterospathodus pennatus* ssp. indet.	*Walliserodus sanctclairi*
78MA-2.0	0.5		1			2														2			
80MA-3	1.0		9	3		5								7			12			2		1	1
80MA-4	2.0		13	6		4	1	1	1			5	1	16		1	24	12		9	1	6	3
80MA-6	4.0		7			2			1			2		6		4	22	1				2	3
80MA-8	6.0		3			4						1	1	1			10	1					1
80MA-10	8.0		11	7	1	2						3	2	9		1	14	2		4		5	2
80MA-12	10.0		6	6		4								7			13	1		12			1
80MA-14	12.0		7	2		3						2		3		1	15	3		12			
80MA-16	14.0		7	3		8	1					1		5		1	19	3		7			
80MA-18	16.0		5	4		1								10		2	12						
80MA-20	18.0		11	5	1	4						6		29		1	19	4		4			2
80MA-22	20.0		1									2		3		1	1	1					
80MA-24	22.0		6	1		13							1	7			8			2	1		1
80MA-26	24.0		19	6	1	11						9		28			24	9		4			1
80MA-28	26.0		20	20		11						8		24			13	7		15			
80MA-30	28.0		3			4			1			1					11	1					1
80MA-34	32.0		4	1		1						3				2	8	4	1		1		1
83MK1-0	33.3		7	5	1	2						6					8	4		3			
83MK1-0.5	33.8		1										2?				1						
80MA-36	34.0		2			1						4					5	3		1			
83MK1-1.0	34.3		3			2						2					10	6			2		
83MK1-1.5	34.8		3	4		2						3					6	1		3	2		
83MK1-2.0	35.3		1			2						2											
80MA-38	36.0		2														3				5		
83MK1-3.0	36.3		<1														1			1			
83MK1-4.0	37.3		1									2					1						
83MK1-5.0	38.3		<1		1	1		1?															
83MK1-6.0	39.3		2			3	2										3	1		1			
83MK1-6.7	40.0		6	4		4	1	2				6	2				15	7		4			
83MK1-8.7	42.0		2	1		1		3					4					14					
80MA-44	42.0		1			1											2						
80MK-1	42.0		1									2						1					
80MK-2	42.0+	Base	56					3				25	8				114	51					10
80MK-3	43.0	1.0	2		1					1					1		2	2					
80MK-4	43.0	1.0	5					1				3					8	6					1
80MK-5	44.0	2.0	5		5					2		2			2		14	1					19
80MK-6	45.0	3.0	1												2		9	3					
80MK-7	46.0	4.0	2		1					1		2					1	2					
80MK-8	47.0	5.0	4							1		22			2		3	9					
80MK-10	48.0	6.0	1							1		1					1	1					
80MK-11	49.0	7.0	2							1					2		11	2					
80MK-12	50.0	8.0	15							3		14			66		42	3					1
83MK1-17.7	51.0	9.0	5									3			12		5						1
80MK-13	52.0	10.0	19		1					1		18			81		50	11					1
83MK1-20.5	53.8	11.8	1									2					1						
83MK1-20.8	54.1	12.1	1									3											
83MK1-21.7	55.0	13.0	3								1	11					3						

*For stratigraphy of section 78MA/80MA/80MK and section 83MK1, from which samples were collected in this region, see Figure 1. See Materials and Methods for precise collecting localities of sections.

Only the lowermost Bisher was sampled at a section in northern Highland County (Fig. 1, section 4). Samples yielded a conodont fauna representative of the *ranuliformis* Zone. They did not yield any representatives of *Ozarkodina sagitta rhenana* or *O. confluens,* which were instrumental for the zonation of the Bisher in the more southern portion of the study area. A section in northern Highland County, sampled for conodonts as part of a study-in-progress by the author on the Silurian Niagaran formations overlying the Bisher, yielded representatives of both species. The Bisher in northern Highland County is within the lower *ranuliformis* Zone and is middle early to late early Wenlockian (Fig. 3, section 4).

The Estill-Bisher contact was exposed at two sections sampled in Adams County (Fig. 1, sections 1 and 2) and was sharp and wavy, as has been recognized (Rexroad et

TABLE 2.
Conodont distribution in Estill Shale and Bisher Formation in a section near Leesburg, Ohio.

Sample number*	Meters above section base	Meters above Bisher base	Conodonts per kilogram	*Carniodus carnulus*	*Decoriconus fragilis*	*Distomodus staurognathoides*	*Kockelella ranuliformis*	*Oulodus petila*	*Oulodus* sp.	*Ozarkodina excavata*	*Ozarkodina polinclinata*	*Panderodus* sp. cf. *P. recurvatus*	*Panderodus unicostatus*	*Pseudooneotodus bicornis*	*Walliserodus sanctclairi*
81MA-0	0.0		4							2	2		5		
81MA-1.5	1.5		7			3		1		2			15	1	
81MA-3.0	3.0		3	1						1			6	1	
81MA-4.5	4.5		3	1	1	5				2			1		
81MA-6.0	6.0		2	1						2			1	2	
81MA-7.5	7.5		3							2		1	2	1	4
81MA-9.0	9.0		8							12			13	10	5
81MA-9.0+	9.0+	BASE	9						2	7			21	10	9
81MA-9.0++	9.3	0.3	13				7		5	20			21	26	1

*For stratigraphy of section, see Figure 1. See Materials and Methods for precise collecting locality of section.

TABLE 3.
Conodont distribution in Bisher Formation in a section near Sinking Spring, Ohio.

Sample number*	Meters above section base	Meters above Bisher base**	Conodonts per kilogram	*Kockelella ranuliformis*	*Oulodus* sp.	*Ozarkodina confluens*	*Ozarkodina excavata*	*Ozarkodina sagitta rhenana*	*Panderous unicostatus*	*Pseudooneotodus bicornis*
81MAB-0	0.0	2.5	<1					1		
81MAB-2.0	2.0	4.5	1				1	12	1	1
81MAB-3.5	3.5	6.0	1				5	5	2	4
81MAB-5.0	5.0	7.5	0							
81MAB-6.5	6.5	9.0	2		2		10	3	4	2
81MAB-8.0	8.0	10.5	9		1		41	5	42	5
81MAB-9.5	9.5	12.0	3				7	4	17	1
83MK2-0-	10.3	12.8	3			1	3		5	
83MK2-0	10.4	12.9	21		1		50	8	60	2
81MAB-11.3	11.3	13.8	7	1			37	1	22	2

*For stratigraphy of section, see Figure 1. See Materials and Methods for precise collecting locality of section.
**Based on Bisher thickness at this locality as measured by Bowman (1956).

al. 1965). Conodonts in basal Bisher samples from both localities had either a pale yellow or gray to black-gray color. Conodonts of the two colors were present in approximately equal numbers. Several of the gray to black-gray conodonts were examined using a scanning electron microscope and an attached energy dispersive x-ray analyzer. The color was due to a coating on the surface of the conodonts. The coating was composed of aluminum, silicon, phosphorus, calcium, and iron. Conodonts are composed primarily of calcium phosphate. Thus, the additional presence of iron, aluminum, and silicon indicated that the conodonts were probably coated with chamosite, a ferrous aluminosilicate (see Depositional Environment for possible significance of chamosite coating on conodonts). Over 75% of the coated conodonts were broken, compared to less than 50% of the pale yellow conodonts. Some of the coated conodonts were visibly abraded, whereas the pale yellow conodonts showed little or no evidence of abrasion. All of the conodont species represented in the basal Bisher were represented by both types of conodonts, except for *Ozarkodina hadra*. It was represented by only gray to black-gray, coated conodonts. *Ozarkodina hadra* was the only species of those represented in the basal Bisher that was not represented in any other Bisher samples. It was also the only species represented in the basal Bisher that has never been reported in North America from a zone succeeding the *amorphognathoides* Zone (the Bisher is within the *ranuliformis* Zone).

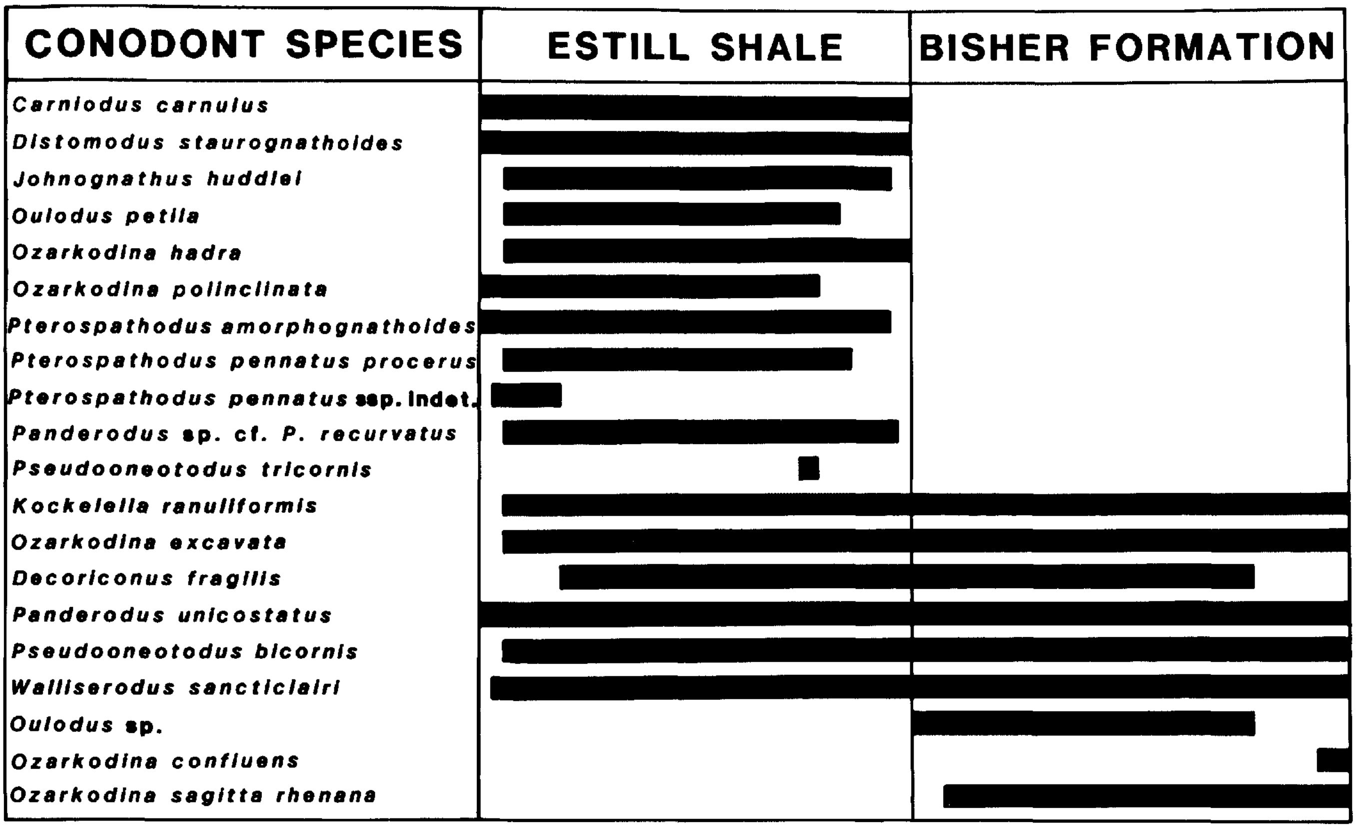

FIGURE 2. Summary range chart of conodont species of the Estill Shale and Bisher Formation.

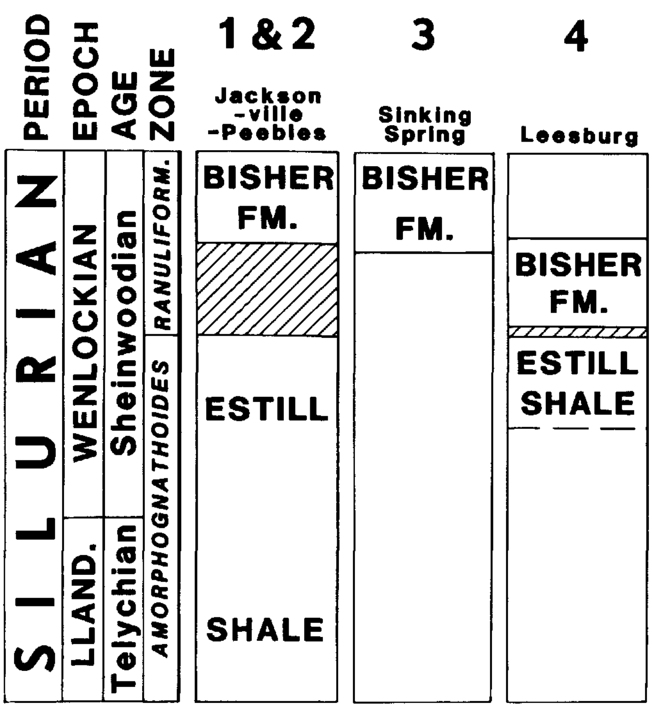

FIGURE 3. Correlation chart of the Estill Shale and Bisher Formation at the four localities studied in southern Ohio. Ages and conodont zonations for the Estill and Bisher are shown to the left of the sections (LLAND. = Llandoverian, RANULIFORM. = *ranuliformis*). Sections are numbered as in Figure 1; diagonal lines indicate an unconformity.

The gray to gray-black, chamosite-coated conodonts are interpreted to be reworked conodonts because of 1) the high percentage of broken specimens, 2) visible abrasion of some of the specimens, and 3) the reported range of *Ozarkodina hadra* in North America, and its distribution in Bisher samples. Reworked conodonts in basal Bisher samples from both Adams County sections included representatives of species that were also distributed throughout the Estill Shale, but were more abundant in the upper part of that formation (*Ozarkodina excavata, O. hadra, Kockelella ranuliformis,* and *Pseudooneotodus bicornis*). The conodont biostratigraphy of the Adams County sections (Fig. 3, sections 1 and 2), showed that an amount of time equivalent to the early *ranuliformis* Zone elapsed before the basal Bisher was deposited on the Estill. This indicated that the Estill-Bisher contact is an unconformity in Adams and probably southern Highland counties (Fig. 3, sections 1 and 2). The sea transgressed over the exposed and eroded upper Estill and reworked conodonts from that part of the Estill into basal Bisher deposits.

The nature of the Estill-Bisher contact in northern Highland County was not as clear. The contact at a section near Leesburg (Fig. 1, section 4) was gradational rather than sharp and wavy. The conodont biostratigraphy in northern Highland County indicates the possibility that no time elapsed between deposition of the uppermost Estill and basal Bisher, or that the Estill-Bisher contact is conformable. Conodonts in the basal Bisher in northern Highland County were either pale yellow or gray to black-gray in color, as they were in the basal Bisher in Adams County. Conodont abundance in the basal Bisher in northern Highland County was considerably less than in the basal Bisher of Adams County (9 conodonts per kg vs. 56 conodonts per kg). The ratio (1:3) in northern Highland County of gray to black-gray, chamosite-coated, reworked conodonts to pale yellow, indigenous conodonts was also reduced compared to the ratio (1:1) in Adams County.

Fewer reworked conodonts in the basal Bisher in northern Highland County could indicate that, although part of the upper Estill was eroded in that region, not as much of it was eroded as was in Adams County. This suggests that the Estill Shale was not exposed for as long a time in the northern part of the study area as it was in the southern part. Thus, the Estill-Bisher contact is an unconformity in northern Highland County, but it represented less time than it did in Adams County (Fig. 3, compare section 4 to sections 1 and 2).

DEPOSITIONAL ENVIRONMENT. Only a few investigators have speculated on the depositional environments of the Estill Shale and Bisher Formation. Bowman (1956) suggested that the water was apparently rather deep during deposition of the Estill. Kleffner (1982, 1984) and Rexroad and Kleffner (1984) used conodont distribution to suggest that the Estill accumulated in a gradually shoaling sea. Kleffner (1982) speculated that the sea eventually regressed from Adams and Highland counties, Ohio, and that the upper part of the Estill Shale was exposed and eroded before the sea transgressed over the two counties to begin deposition of the Bisher. Bowman (1956) stated that the Bisher Sea possibly became more shallow shortly after initial deposition of the Bisher, when the *Cryptothyrella* lithofacies was deposited, and became deeper again afterwards. Kleffner (1984) suggested that conodont distribution in the Bisher indicated deposition in a near-shore environment.

The *amorphognathoides* Zone conodont fauna of the Estill Shale is similar to a conodont fauna from the same interval in the Welsh Basin of the British Isles. Variations have been shown in the distribution of conodonts across the shelf sea of the Welsh Basin during this interval (Aldridge and Mabillard 1981). Relative abundances of the more common species of the Welsh Basin from mid-shelf and near-shore localities were compared with relative abundances of the same species from the lower/middle Estill and upper Estill (Fig. 4). The trends noted in comparing abundance patterns from the mid-shelf and near-shore localities of the Welsh Basin to the abundance patterns in the lower/middle Estill and upper Estill were remarkably similar (Fig. 4). Seven of the eight species compared showed the same trends; only *Pseudooneotodus bicornis* differed.

Carniodus carnulus, *Panderodus* sp. cf. *P. recurvatus* (Rhodes), *Panderodus unicostatus* (Branson and Mehl), and *Pterospathodus amorphognathoides* were more abundant at mid-shelf than at near-shore localities in the Welsh Basin (Aldridge and Mabillard 1981), and were also more abundant in the lower/middle Estill than in the upper Estill.

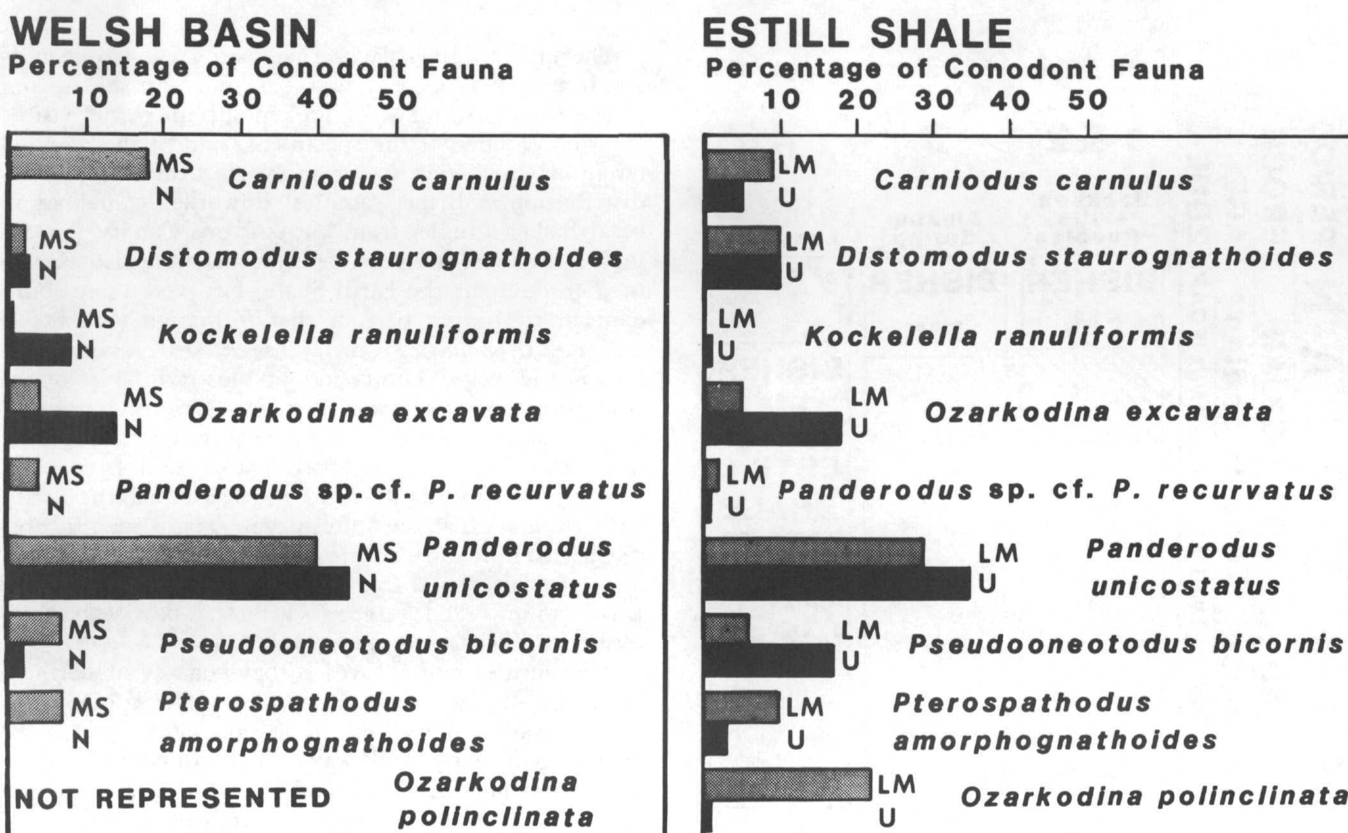

FIGURE 4. Conodont abundances of the more common species in the *amorphognathoides* interval of the Welsh Basin of the British Isles and the Estill Shale in southern Ohio. MS, mid-shelf; N, near-shore; LM, lower/middle Estill; U, upper Estill. NOT REPRESENTED refers to Aldridge and Mabillard (1981, Figs. 1.2 and 1.3), and only means that *Ozarkodina polinclinata* was not a common species at the localities they sampled. Thus, its distribution was not included in their study.

Kockelella ranuliformis and *Ozarkodina excavata* were more abundant at near-shore than at mid-shelf localities in the Welsh Basin, and were also more abundant in the upper Estill than in the lower/middle Estill. These similarities suggest that the lower/middle Estill Shale was deposited farther offshore in deeper water than the upper Estill, and that the Estill was deposited in a shoaling sea.

Chamosite-coated conodonts in the basal Bisher, interpreted to be reworked from the upper Estill, were additional evidence for a shoaling Estill Sea. Chamosite generally formed in shallow marine waters in which reducing conditions prevailed, as in marginal seas (Simpson 1966). Oolitic ironstones in Europe characteristically consist of chamosite ooids in a matrix of chamosite mud or siderite microspar, and frequently marked the late stages of regional regressions (Hallam and Bradshaw 1979). Absence of chamosite deposits from the uppermost Estill throughout the study area suggests that following the stage of regression that was responsible for the depositional environment in which conodonts were coated with chamosite, the Estill Sea regressed from Adams and Highland counties. The upper part of the Estill, including the chamosite deposits, was exposed, eroded, and the more resistant components (conodonts) were eventually reworked into the southward transgressive basal Bisher deposits.

An Estill depositional history based on conodont distribution corresponds well with the sedimentologic record of the formation. The lower/middle Estill, which consisted primarily of clay shale, was deposited during the late Llandoverian in a relatively deep, subtidal environment below storm wave base. The upper Estill, which consisted of arenaceous shales and abundant, thin, cross-bedded, arenaceous dolomites, was deposited during the early Wenlockian in a more shallow, subtidal environment above storm wave base, probably not far below fair-weather wave base.

The *ranuliformis* Zone conodont fauna of the Bisher had only four species in common with a conodont fauna from a post-*amorphognathoides* interval of the Welsh Basin (Aldridge and Mabillard 1981) of the same, or perhaps slightly older, age. Only one (*Decoriconus fragilis*) of those four species has a distribution in the Welsh Basin that makes it useful as a paleoecological indicator in the Bisher. *Decoriconus fragilis* has its greatest abundance at off-shore localities and is rare or absent at near-shore localities in the Welsh Basin. *Decoriconus fragilis* was a rare component of the Bisher fauna, which suggests that the Bisher was deposited in a near-shore environment in relatively shallow subtidal conditions. *Kockelella ranuliformis* is fairly common only at localities nearest to the shore during the *amorphognathoides* interval of the Welsh Basin, and is rare or absent at all other localities (Aldridge and Mabillard 1981). It does not occur in the post-*amorphognathoides* interval of the Welsh Basin (Aldridge and Mabillard 1981, Aldridge 1985). *Kockelella ranuliformis* was extremely rare or absent in all but the base of the Bisher. If the post-*amorphognathoides* interval distribution of *K. ranuliformis* was the same as its *amorphognathoides* interval distribution, its distribution in the Bisher indicates that water depth was shallowest at the beginning of Bisher deposition. This is in accord with the basal Bisher representing the first deposits of a transgressing sea.

Systematic Paleontology. All of the conodont species represented in the Estill Shale and Bisher Formation (Fig. 2), with the possible exception of *Oulodus* sp., have been well described in the literature (Ziegler 1973, Aldridge 1975, Barrick and Klapper 1976, Cooper 1976, Barrick 1977, Ziegler 1977, Ziegler 1981, Barrick 1983, Aldridge 1985). Since there is little that this study can add to those descriptions, no formal systematics are presented. The taxonomy of *Oulodus* sp. and the significance of the distributions of *Ozarkodina polinclinata* (Nicoll and Rexroad) and *O. sagitta rhenana* are presented in the Appendix.

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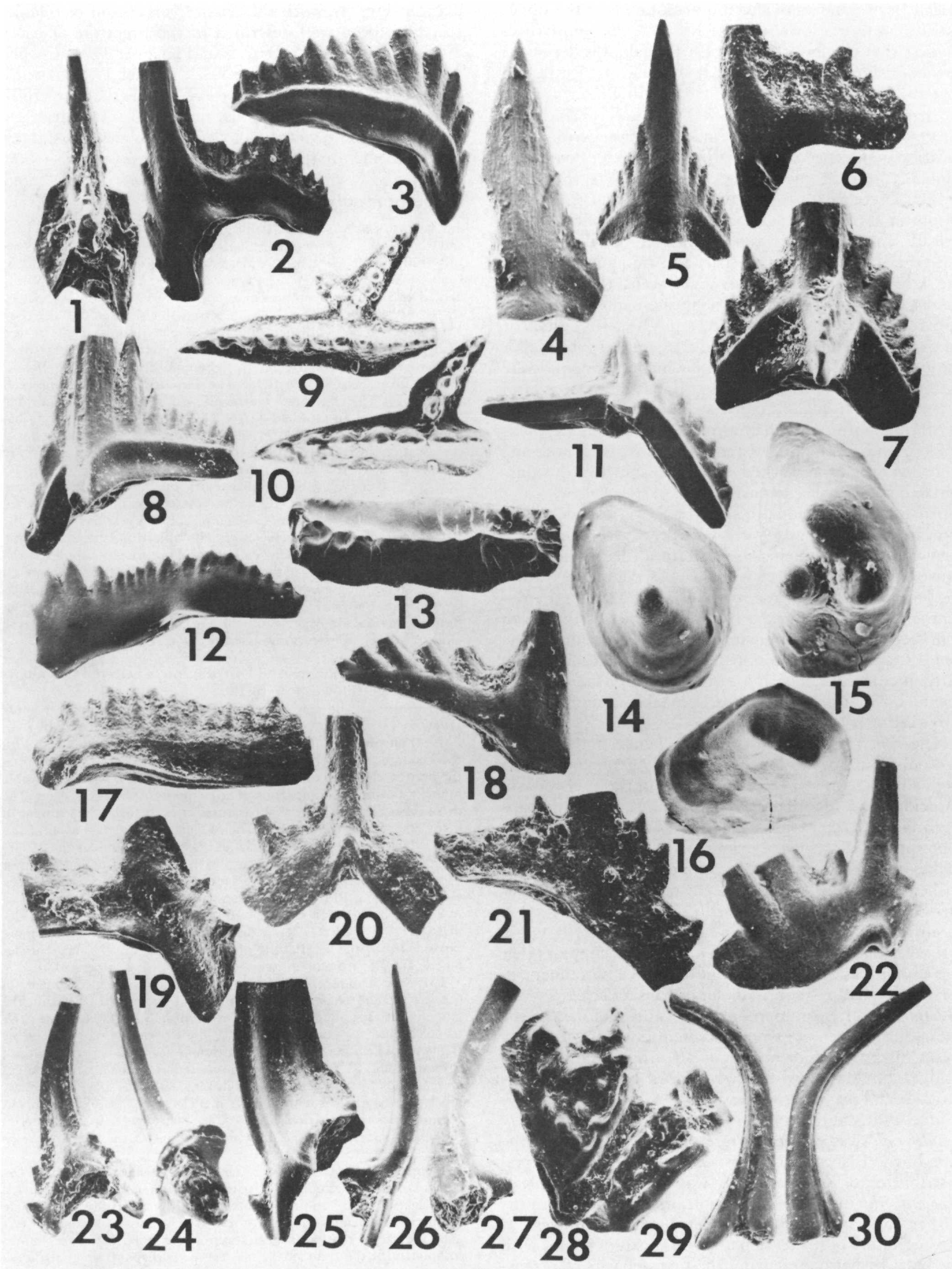
APPENDIX. **Taxonomy And Distribution of Selected Conodonts**
OULODUS SP. (FIG. 6, PMS 10-14).

Description: The apparatus of this species is similar to that of *Delotaxis* (=*Oulodus*) sp. A Barrick and Klapper. The Pb (Fig. 6, PM 12) and Sc (Fig. 6, PM 11) elements are nearly identical with their counterparts in *D.* sp. A. The posterior process is broken off on the only Sc elements recovered (two), however, so it was not possible to make a complete comparison of Sc elements of the two species. The three other elements in the apparatuses of both species are similar in many respects, but also differ. The M element (Fig. 6, PM 10) has a cusp which is rounded anteriorly and posteriorly, unlike the M element of *D.* sp. A, which has a cusp with sharp anterior and posterior edges. It also appears to have a better developed anticusp. The Sa element (Fig. 6, PM 14) differs from its counterpart in *D.* sp. A only in that its lateral processes are curved more posteriorly. The Sb element (Fig. 6, PM 13) has a basal cavity which is slightly more expanded than the basal cavity of the Sb of *D.* sp. A. The denticles on the anterior process are rounded, rather than compressed.

Remarks: The morphological differences between the elements of *Oulodus* sp. and *Delotaxis* sp. A are trivial enough to be within the range of intraspecific variability. The small number of elements of *O.* sp. recovered for study, incomplete preservation of the M and Sc elements (which permit the recognition of *Delotaxis* sp. A according to Barrick and Klapper 1976), and differences in the observed ranges of *O.* sp and *D.* sp. A were the reasons for leaving the species of *Oulodus* represented in the Bisher in open nomenclature. *Oulodus* sp. occurs in the lower and middle *ranuliformis* Zone, whereas *D.* sp. A occurs in the upper part of the succeeding *amsdeni* Zone to the lower *variabilis* Zone.

Elements of *Oulodus* sp. were rare in the Bisher; elements of *Delotaxis* sp. A were rare in the Clarita Formation in Oklahoma (Barrick and Klapper 1976), and not reported from the age-equivalent Wayne Formation in Tennessee (Barrick 1983). The rarity of elements is a good indication that both species were never more than a very minor component of the conodont fauna, except perhaps in restricted areas not yet represented in strata studied. Observed ranges of rare species are more likely to be incomplete, which would help to explain the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discrepancy in the ranges of *O.* sp. and *D.* sp. A, if the two species are conspecific.

Range: Lower and middle *ranuliformis* Zone.

Material studied: 9 Pb elements, 2 M elements, 6 Sa elements, 2 Sb elements, 2 Sc elements.

***OZARKODINA POLINCLINATA* (FIG. 5, PMs 17-22).** The trend in abundance of this species in the Estill Shale was the same for species in the Estill that are more abundant at mid-shelf than at near-shore localities in the Welsh Basin (Fig. 4). *Ozarkodina polinclinata* was a major component (over 20%) of the lower/middle Estill conodont fauna, but only a very minor component (<0.5%) of the upper Estill conodont fauna. Elements of the species were completely absent from the upper 9 m of the Estill (Tables 1 and 2, Fig. 2). Either *O. polinclinata* became extinct within, rather than at the end, of the *amorphognathoides* Zone, or it was extremely sensitive to changes in the depositional environment from the lower/middle to upper Estill (relatively deeper, quiet-water, one subtidal environment to relatively shallower, sometimes agitated-water, subtidal environment). *Ozarkodina polinclinata* has been reported to range to the end of the *amorphognathoides* Zone (Barrick and Klapper 1976, Barrick 1983), so the latter possibility best explains the distribution of this species in the Estill. Since *O. polinclinata* was cosmopolitan during the late Llandoverian and early Wenlockian, its abundance in samples from strata of that age is an excellent paleoecological indicator worldwide.

***OZARKODINA SAGITTA RHENANA* (FIG. 6, PMs 1-7).** This species was an important part of the Bisher conodont fauna. Elements of *O. sagitta rhenana* occurred in over 60% of the Bisher samples and in all Bisher samples that yielded four or more conodonts per kg. It composed over 24% of the Bisher conodont fauna, but had an irregular distribution. Four samples, three between 8 and 10 m above the base of the formation, accounted for over 80% of the elements of this species. *Ozarkodina sagitta rhenana* composed almost 52% of the conodont fauna of those samples, but it made up only 5% of the conodont fauna in the remaining Bisher samples. Jeppsson (1979) noted a similar irregular distribution for *O. sagitta* and observed that it has a narrow ecological range, often occurring only where other conodonts are rare or absent. Aldridge and Jeppsson (1984) observed the same irregular distribution and added that *O. sagitta rhenana* had a tolerance which seemed to have extended into some areas of very shallow sea. Neither study (Jeppsson 1979, Aldridge and Jeppsson 1984) elaborated on what the parameters of the narrow ecologic range of *O. sagitta* were.

The four Bisher samples dominated by *Ozarkodina sagitta rhenana* did not exhibit any lithologic or paleobiologic (except for abundance of this species) differences from most other Bisher samples. The ecological conditions responsible for this species flourishing in certain horizons of the Bisher are apparently not represented in the preserved strata. *Ozarkodina sagitta rhenana* has potential for being an excellent paleoecological indicator, if future studies can determine what those paleoecological conditions are.

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FIGURE 5. Scanning electron microscope photomicrographs (PMs) of conodonts from the Estill Shale and Bisher Formation. **PMs 1-7:** *Carniodus carnulus* Walliser. 1, posterior view of Sa element, OSU 36488, × 85, collection 80MA-28; 2, lateral view of Sb element, OSU 36484, × 80, collection 80MA-14; 3, lateral view of Pb element, OSU 36485, × 85, collection 80MA-10; 4, lateral view of M element, OSU 36490, × 100, collection 80MA-18; 5, lateral view of Pa element, OSU 36486, × 65, collection 80MA-28; 6, lateral view of Sc element, OSU 36491, × 100, collection 80MA-28; 7, lateral view of Pa element with a lateral process, OSU 36489, × 100, collection 80MA-16. **PMs 8,9,11:** *Pterospathodus amorphognathoides* Walliser. 8, lateral view of S element, OSU 36466, × 70, collection 80MA-12; 9, top view of Pa element, OSU 36465, × 55, collection 80MA-14; 11, lateral view of Pb element, OSU 36467, × 40, collection 80MA-36. **PM 10:** *Pterospathodus pennatus procerus* (Walliser). Top view of Pa element, OSU 36512, × 100, collection 80MA-4. **PM 12:** *Ozarkodina hadra* (Nicoll & Rexroad). Lateral view of Pa element, OSU 36474, × 30, collection 80MA-8. **PM 13:** *Johnognathus huddlei* Mashkova. Top view of Pa element, OSU 36451, × 35, collection 80MA-4. **PMs 14,16:** *Pseudooneotodus bicornis* Drygant. 14, top view of one denticle squat conical element (*Pseudooneotodus beckmanni* (Bischoff & Sannemann)), OSU 36482, × 155, collection 80MK-13; 16, top view of two denticle squat conical element, OSU 36480, × 75, collection 80MK-2. **PM 15:** *Pseudooneotodus tricornis* Drygant. Top view of three denticle squat conical element, OSU 36481, × 180, collection 80MA-34. **PMs 17-22:** *Ozarkodina polinclinata* (Nicoll & Rexroad). 17, lateral view of Pa element, OSU 36456, × 55, collection 80MA-28; 18, lateral view of M element, OSU 36453, × 75, collection 80MA-18; 19, lateral view of Sc element, OSU 36452, × 100, collection 80MA-20; 20, posterior view of Sa element, OSU 36455, × 70, collection 80MA-28; 21, lateral view of Pb element, OSU 36457, × 100, collection 80MA-28; 22, lateral view of Sb element, OSU 36454, × 135, collection 80MA-10. **PMs 23-28:** *Distomodus staurognathoides* (Walliser). 23, lateral view of Sa element, OSU 36472, × 65, collection 80MA-28; 24, aboral-lateral view of Pb element, OSU 36469, × 90, collection 80MA-8; 25, lateral view of M element, OSU 36470, × 40, collection 80MA-24; 26, lateral view of Sc element, OSU 36471, × 35, collection 80MA-44; 27, Lateral view of Sb element, OSU 36468, × 40, collection 80MA-28; 28, top view of Pa element, OSU 36473, × 60, collection 80MA-28. **PMs 29,30:** *Panderodus* sp. cf. *P. recurvatus* (Rhodes). 29, lateral view of costate element, OSU 36504, × 80, collection 80MA-26; 30, lateral view of simplexiform element, OSU 36503, × 75, collection 80MA-6.

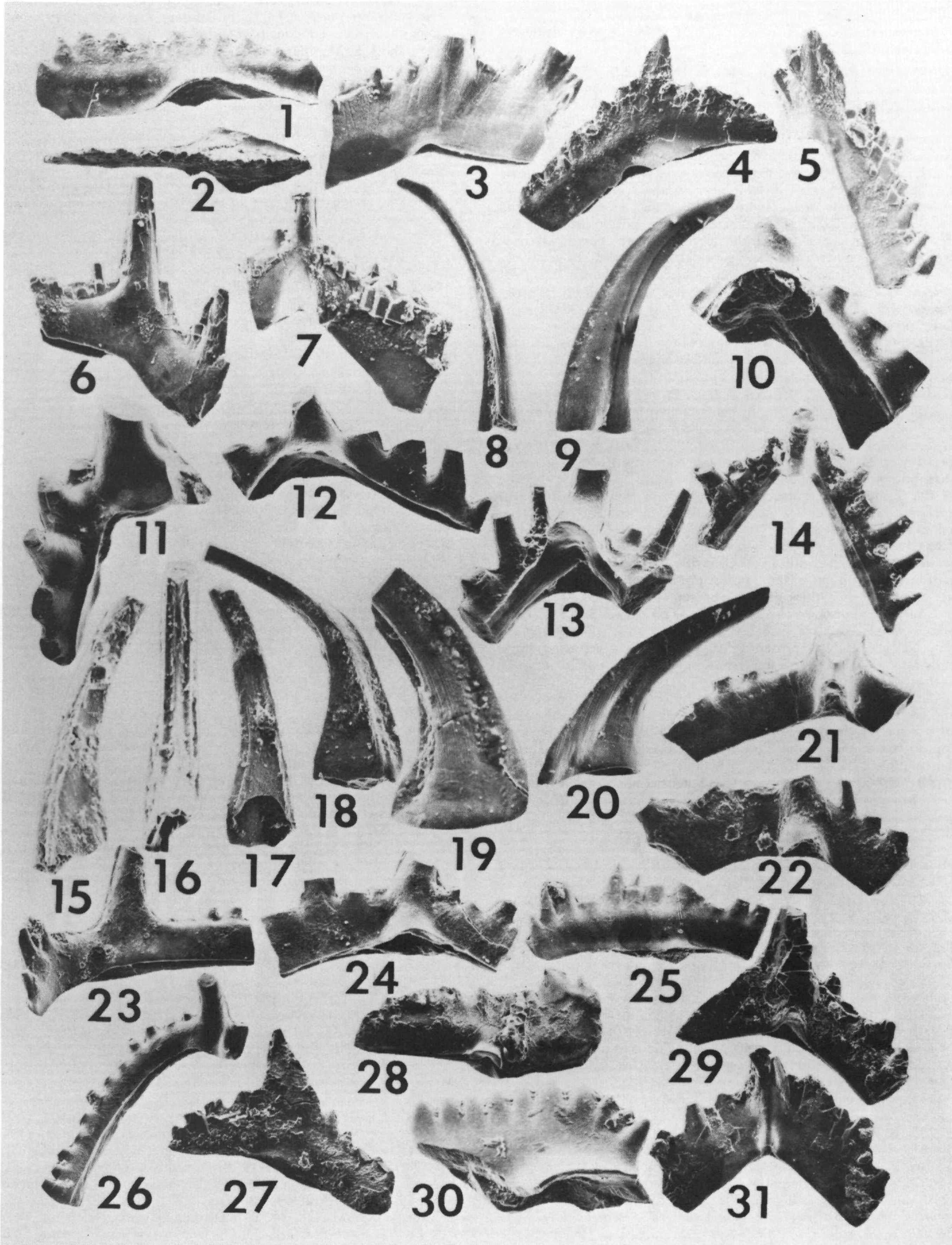
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FIGURE 6. Scanning electron microscope photomicrographs (PMs) of conodonts from the Estill Shale and Bisher Formation. **PMs 1-7:** *Ozarkodina sagitta rhenana* (Walliser). 1, lateral view of Pa element, OSU 36497, × 55, collection 80MK-12; 2, top view of Pa element, OSU 36436, × 65, collection 80MK-13; 3, lateral view of Sb element, OSU 36441, × 120, collection 80MK-13; 4, lateral view of Pb element, OSU 36439, × 70, collection 80MK-13; 5, lateral view of M element, OSU 36440, × 90, collection 80MK-13; 6, lateral view of Sc element, OSU 36443, × 120, collection 80MK-13; 7, posterior view of Sa element, OSU 36442, × 120, collection 80MK-12. **PMs 8,9:** *Panderodus unicostatus* (Branson & Mehl). 8, lateral view of costate element, OSU 36502, × 75, collection 80MA-16; 9, lateral view of simplexiform element, OSU 36501, × 80, collection 80MA-6. **PMs 10-14:** *Oulodus* sp.. 10, lateral view of M element, OSU 36479, × 70, collection 81MAB-6.5; 11, lateral view of Sc element, OSU 36477, × 55, collection 81MAB-6.5; 12, lateral view of Pb element, OSU 36475, × 55, collection 80MK-5; 13, lateral view of Sb element, OSU 36476, × 70, collection 80MK-5; 14, posterior view of Sa element, OSU 36478, × 40, collection 80MK-11. **PMs 15-18:** *Walliserodus sancticlairi* Cooper. 15, lateral view of M element, OSU 36496, × 130, collection 81MK-4; 16, posterior view of Sa element, OSU 36493, × 110, collection 80MK-5; 17, lateral view of Sb element, OSU 36495, × 70, collection 80MK-2; 18, lateral view of Sd element, OSU 36494, × 80, collection 80MA-24. **PMs 19, 20:** *Decoriconus fragilis* (Branson & Mehl). 19, lateral view of Sb element, OSU 36492, × 130, collection 81MA-9.0; 20, lateral view of Sc element, OSU 36497, × 125, collection 80MK-5. **PMs 21-26:** *Ozarkodina excavata* (Branson & Mehl). 21, posterior view of Sa element, OSU 36444, × 75, collection 81MAB-8.0; 22, lateral view of Sb element, OSU 36447, × 85, collection 80MK-12; 23, lateral view of Sc element, OSU 36449, × 65, collection 81MAB-11.3; 24, lateral view of Pb element, OSU 36446, × 85, collection 81MAB-8.0; 25, lateral view of Pa element, OSU 36448, × 45, collection 81MAB-8.0; 26, lateral view of M element, OSU 36445, × 50, collection 81MAB-8.0. **PMs 27,28,29,31:** *Ozarkodina confluens* (Branson & Mehl). 27, lateral view of Pb element, OSU 36509, × 45, collection 81MK-5; 28, lateral view of Pa element, OSU 36508, × 30, collection 81MK-6; 29, lateral view of Sb element, OSU 36505, × 60, collection 81MK-5; 31, posterior view of Sa element, OSU 36510, × 70, collection 81MK-8. **PM 30:** *Kockelella ranuliformis* (Walliser). Lateral view of Pa element, OSU 36483, × 60, collection 80MK-4.

The 1986 Paper Of The Year Award

was presented at the 96th Annual Meeting
of the OAS at Malone College, Canton
on 25 April 1987 to:

Lisa A. Whiteside and Brooks M. Burr

Department of Zoology
Southern Illinois University
Carbondale, IL

for their paper

"Aspects of the Life History of the Tadpole Madtom,
Noturus gyrinus (Siluriformes: Ictaluridae),
in Southern Illinois"

The Ohio Journal of Science 86: 153-160